Final Technical Report
Grant Number 04HQGR0048

“REAL-TIME GLOBAL EARTHQUAKE”

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Non-Technical Summary

In recent years, geologists and geophysicists have witnessed a revolution in the development and implementation of an array of new tools for measuring motions of the earth's crust, including global positioning satellites, interferometric synthetic aperture radar, and broadband digital seismic systems, allowing tremendous advances in motion detection accuracy. As demonstrated in this report, we can successfully model the near-in data with far-fewer parameters than reported to date using our recently developed analytical tools (wavelet transforms, modified annealing, etc.). We demonstrate the reverse process of predicting local shaking from teleseismic data as well. Thus we can make rapid assessments of earthquake damage following major global events which proves very useful in providing emergency services.

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Investigations

We have been working with a team of USGS researchers to provide rapid assessment of earthquake damage following major global events. The best fitting distributed fault models for over 10 events have been generated using waveforms collected by the NEIC's automated system, and their best fitting point-source estimates, see NEIC web page. Analytically based shakemaps based on these finite source solutions for some of the largest events are discussed in *Ji, Wald, and Helmberger* (2004). While lessons learned from these first two years of study are many, a few issues are apparent; (1) Fault complexity involving a mixture of mechanisms (Denali), (2) Epicenter mislocation generated with models without slabs, and (3) Important smaller events where directivity is less obvious (San Simeon), but important in terms of characteristics.

Results

1. A teleseismic study of the 2002 Denali, Alaska, earthquake and implications for rapid strong motion estimation

Chen Ji, Don V. Helmberger and David J. Wald

Abstract. Rapid slip histories for the 2002 Denali, Alaska, Earthquake were derived from the global teleseismic waveform data. Three models indicates a step-wise improvement in matching the waveform data and in recovery of the rupture details by applying the wavelet inversion procedure discussed in [*Ji et al.*, 2002a]. The first model, referred to as Phase I, is analogous to an automated solution where a simple fault plane (300 km long) is fixed based on the preliminary CMT (Harvard) mechanism and assuming the PDE epicenter. The initial fits to the early portion of the P waves were poor since they do not display a strike-slip polarity pattern expected from the CMT mechanism. To improve this result, we first implemented a more realistic fault geometry using the Denali fault trace inferred from DEM topography in Phase II. While this produced some improvements, major waveform misfits still remained. We then calibrated path effects for P-wave and SH-wave arrival times using a comparably simple nearby foreshock, the 2002 Nenana, Alaska, earthquake. Time shifts of up to 4 sec for P waves and up to 8 sec for SH wave relative to *IASPEI91* travel-time table were found. Applying these corrections revealed some discrepancies in the rupture initiation. To produce a consistent picture requires at least 4 fault segments referred to as A, B, C and D. A weak rupture initiated on a strike-slip Denali fault branch A at a depth of 10 km where a low angle thrust fault plane B intersects A. After about 2 sec, a major event occurred on plane B (strike=221^{o}, dip=35^{o}) and dominated the rupture for the next 8 sec. When rupture B reached the surface, at about 10 sec after initiation, the major portion of the Denali fault (segment C) ruptured eastward with a relatively fast velocity (3 km/sec) producing a large slip concentration (up to 9 m at a depth of 10 km). The surface slip is about 7 m along a 30 km long segment. This feature is near the intersection of the Denali fault and the Totschunda fault (branch D). The rupture on D is

relatively shallow (less than 15 km) while the extension beyond the intersection on the Denali fault displays deeper slip. The entire rupture extends over 90 sec and has an overall seismic moment of 1.1x10^{21} Nm with a centroid depth of 16.8 km. These models were used to predict the ground velocity and shaking intensity field in the fault vicinity. Peak velocities of over 2 m/sec occurred above the major surface offsets. The procedure using the teleseismic data to estimate local strong motions could be automated and used for global realtime earthquake shaking and damage assessment.

2. Slip history of the 2003 San Simeon earthquake constrained by combining 1-Hz GPS, strong motion, and teleseismic data

Chen Ji, Kristine M. Larson, Ying Tan, Kenneth W. Hudnut, and Kyuhong Choi

Abstract. The slip history of the 2003 San Simeon earthquake is constrained by combining strong motion and teleseismic data, along with GPS static offsets and 1-Hz GPS observations. Comparisons of a 1-Hz GPS time series and a co-located strong motion data are in very good agreement, demonstrating a new application of GPS. The inversion results for this event indicate that the rupture initiated at a depth of 8.5 km and propagated southeastwards with a speed ~3.0 km/sec, with rake vectors forming a fan structure around the hypocenter. We obtained a peak slip of 2.8 m and total seismic moment of 6.2 ~ 10^{18} Nm. We interpret the slip distribution as indicating that the hanging wall rotates relative to the footwall around the hypocenter, in a sense that appears consistent with the shape of the mapped fault trace. INDEX TERMS: 1242 Geodesy and Gravity: Seismic deformations (7205); 7212 Seismology: Earthquake ground motions and engineering; 8123 Tectonophysics: Dynamics, seismotectonics. Citation: Ji, C., K. M. Larson, Y. Tan, K. W. Hudnut, and K. Choi (2004), Slip history of the 2003 San Simeon earthquake constrained by combining 1-Hz GPS, strong motion, and teleseismic data, *Geophys. Res. Lett., 31,* L17608, doi:10.1029/2004GL020448.

3. Co-seismic slip history and early afterslip of the 2004 Parkfield earthquake

Chen Ji, K. K. Choi, N. King, K. M. Larson, and K. W. Hudnut

Abstract. We studied the slip history of 2004 (Mw 5.9) Parkfield earthquake using waveforms of three strong motion and 13 1-Hz GPS stations. GPS vectors averaged over 1 day after the mainshock relative to 1 day before were investigated as well. We tested two possible fault orientations. The first one dips $83\deg$ to the northeast, constructed based upon the moment tensor solution and surface trace of the San Andreas fault. Another is a vertical fault plane based upon a recent double-difference relocation study of Waldhauser et al. Considering about 20 \% velocity contrast across the San Andreas fault, we used two velocity structures to calculate the earth response. The slip amplitude, rake angle, rupture initiation time, rupture duration of each subfault are inverted simultaneously. Our preliminary results showed that the vertical plane fits the data better. The total seismic moment of this event is 9x${10}^{24}$ dyne.cm with a peak slip of about 70 cm. This earthquake initiated at a depth of 8 km and rupture northwest for about 22 km with a rupture velocity of 3.0 km/sec. Most slip concentrates in a depth range from 6 to 11 km, roughly filling the gap of two streaks of seismicity from 1969-2002. This preliminary slip model will be further improved by including more strong motion data. The after-slip during the first day of earthquake will also be studied.

4. Slip distribution and rupture history of the 2004 Sumatra-Andaman islands earthquake

Chen Ji, Vala Hjorleifsdottir, Alex Song, Sidao Ni, Jeroen Tromp, Hiroo Kanamori, and Don Helmberger

Abstract. We model the slip-distribution and rupture history of the 2004 Sumatra-Andaman islands earthquake using broadband waveforms downloaded from IRIS DMC. Three individual studies, which cover a frequency band from 0.2 mHz to 5 Hz, have been preformed to understand this complex rupture process. A preliminary model based upon the teleseismic P and SH waves band passed from 2 sec to 200 sec indicates that most of seismic energy within this frequency band radiated from a 450 km long segment of the southern end of the aftershock zone. We have verified this model by matching the static displacement at the nearby GPS site SAMP (Sampali, Medan, Sumatra, 260 km east of the hypocenter). We have also forward-computed long period (80 to 1000 sec) SEM waveforms at all GSN stations. The synthetics fit the observations remarkably well at period of 200 to 500 sec, but display some discrepancy at very long period (500 to 1000 sec). This preliminary result is limited by the duration of the seismic phases used for inversion, which do not contain the energy coming from the northern segment. Our forward modeling of broadband waveforms at nearby station PALK (distance =15 deg.) as well as the discrepancies at very long periods (500 to 1000 s) suggests that some slip occurred as late as 600 sec. This result is consistent with the second analysis, which studies the envelope function of high frequency scattering P waves. Azimuthal variation of the lengths of envelope functions suggests a total rupture length of about 1200 km and rupture duration of 500 sec or longer. The third result is based on the analysis of the normal modes spectrum, which also suggests significant seismic moment released from north portion of fault. To better constrain the slip history of such a long duration earthquake, we are developing finite fault inverse procedures utilizing the longer seismic waveforms and normal-mode spectrums. The inverted result will be verified using the 3D SEM simulation.

References

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